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POWER SUPPLY

INSTRUCTION MANUAL

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OPS

OPERATIONAL AMPLIFIER

MODULAR

design group

Model OPS 72-0.3(C)

Serial No. E-5615.0

INSTRUCTION MANUAL

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2,992,379	3,112,439	3,241,042	3,275,948
2,992,386	3,128,423	3,243,690	3,303,411
3,028,538	3,131,344	3,243,749	3,303,412
3,056,905	3,210,619	3,275,925	3,303,415
3,088,053	3,226,628	3,275,927	3,305,763
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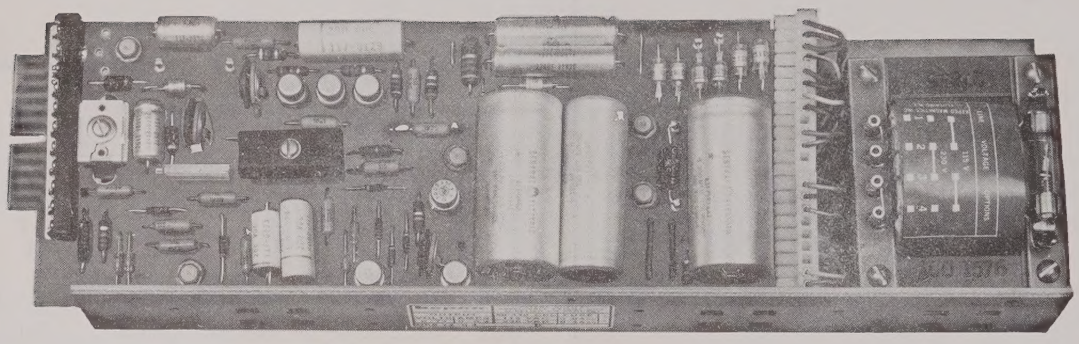
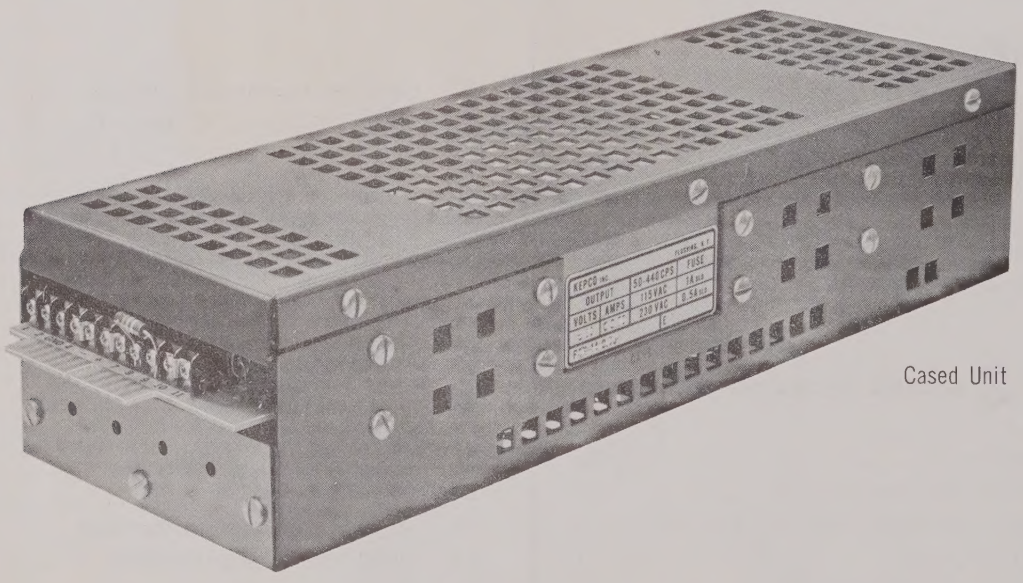
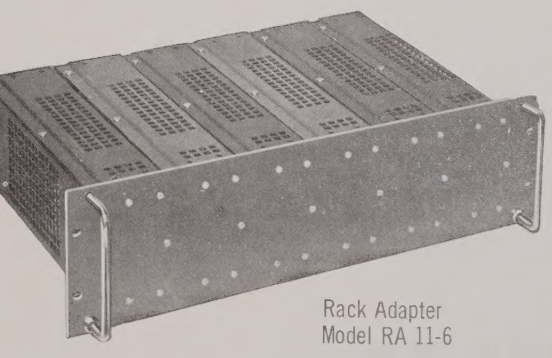


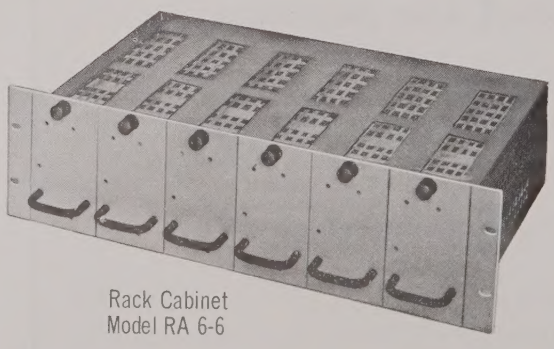
FIG. 1-1: KEPCO MODEL OPS OPERATIONAL POWER SUPPLY /AMPLIFIER (UNCASED)



Cased Unit



Rack Adapter
Model RA 11-6



Rack Cabinet
Model RA 6-6

FIG. 1-2: KEPCO MODEL OPS OPERATIONAL POWER SUPPLY AMPLIFIER (ACCESSORIES)

SECTION 1 INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This instruction manual contains information for the installation, operation and maintenance of the KEPCO Model OPS 7-2 through OPS 100-0.2 Operational Power Supplies/Amplifiers.

1-3 GENERAL DESCRIPTION

1-4 The Kepco Models OPS 7-2 through OPS 100-0.2 are all-silicon, operational power supplies, derived from the Kepco PBX design group. They share with that design group their mechanical outside dimensions and many electrical characteristics such as the sharp current limiting circuit, highly stable reference circuits and wide temperature range, as well as good stability. The programming polarities are the same as the PBX and opposite to the PAX design group, utilizing the (+) plus error-sensing terminal as the common point for the amplifier.

MODEL	DC OUTPUT RANGE		OUTPUT IMPEDANCE	
	VOLTS	AMPS	DC	SOURCE INDUCTANCE
OPS 7–2	0–7	0–2	0.0005	+15 μh
OPS 15–1.5	0–15	0–1.5	0.001	+15 μh
OPS 21–1	0–21	0–1	0.0025	+15 μh
OPS 40–0.5	0–40	0–0.5	0.008	+15 μh
OPS 72–0.3	0–72	0–0.3	0.025	+15 μh
OPS 100–0.2	0–100	0–0.2	0.050	+15 μh

TABLE 1-1: SPECIFICATIONS, OUTPUT

1-5 ACCESSORIES (NOT SUPPLIED)

1-6 The OPS 7-2 through OPS 100-0.2 Operational Power Supplies/Amplifiers are supplied without a line cord and without external feedback components. Connections to and from the units, including AC line connections, may be made either by means of the 11-terminal barrier strip, or with an (optional) mating plug to the printed circuit board connector.

1-7 ELECTRICAL ACCESSORIES:

a) Mating connector for printed circuit board connector: KEPCO Part No. 143-0200 or
CINCH Part No. 250-12-37-200 or
METHODE Part No. CD-612S-P7

1-8 MECHANICAL ACCESSORIES:

a) *Panel Adapter:*
Kepco Model RAP 6-1: $5\frac{1}{4}$"H × $2\frac{25}{32}$"W
(Includes handle and fastener) – for mounting six cased units in Rack Cabinet Kepco Model RA 6-6.

b) *Panel Adapter:*
Kepco Model RAP 7-1: $3\frac{1}{2}$"H × $4\frac{7}{32}$"W
(Includes handle and fastener) – for mounting four cased units in Rack Cabinet Kepco Model RA 7-4.

c) *Filler Panels:*
Kepco Model RFP 7-1 (Fills one space in RA 7-4)
Kepco Model RFP 7-2 (Fills two spaces in RA 7-4)
Kepco Model RFP 6-1 (Fills one space in RA 6-6)
Kepco Model RFP 6-2 (Fills two spaces in RA 6-6)
Kepco Model RFP 6-3 (Fills three spaces in RA 6-6)

d) *Rack Cabinet:*
Kepco Model RA 6-6: $5\frac{1}{4}$"H × 19"W × $13\frac{3}{4}$"D
(for mounting six units)
Kepco Model RA 7-4: $3\frac{1}{2}$"H × 19"W × $13\frac{3}{4}$"D
(for mounting four units)

Special back plates with mounted mating connectors for printed circuit board connectors adapt the rack cabinets for plug-in mounting of the OPS units.

Kepco Model RA 6-6BP: For plug-in mounting six units in Rack Cabinet Kepco Model RA 6-6.

Kepco Model RA 7-4BP: For plug-in mounting four units in Rack Cabinet Kepco Model RA 7-4.

e) *Rack Adapters:*
Kepco Model RA 12-1: $3\frac{1}{4}$"H × 19"W
(for mounting a single OPS-C unit)
Kepco Model RA 11-6: $5\frac{1}{4}$"H × 19"W
(for end mounting six OPS-C units)
Kepco Model RA 13-4: $3\frac{1}{2}$"H × 19"W
(for end mounting four OPS-C units)

1-9 SPECIFICATIONS, GENERAL

a) *Input Requirements:* 105 to 125V AC or 210 to 250V AC, 50 to 440 Hz, single phase.

b) *Ambient Temperature:* –20°C to +60°C maximum.

c) *Storage Temperature:* –40°C to +85°C maximum.

d) *Isolation:* A maximum of 500 volts (DC or p-p) may be connected between chassis and either output terminal.

1-10 SPECIFICATIONS, OPEN LOOP

a) *Output:* The maximum volt-ampere ratings are given in Table 1-1 for each model. Outputs are unipolar (vary in one direction only) and are floating with respect to the chassis. All ratings are for continuous duty at the maximum rated ambient temperature.

b) *Current Limiting:* Adjustable from 10% to 110% of maximum rated output current. Permits continuous operation into a short circuit.

c) *DC Voltage Gain:* In excess of 80 db.

d) *Bandwidth:* 200 kHz at unity gain crossing.
Rolloff slope: –6 db per octave.

e) *Voltage Slewing:* 500,000 volts per second.

f) *Sinusoidal Frequency Response:*

$$f_{max.} = \frac{500{,}000}{\pi E_{pp}} \text{ (Hz)}$$

(where E_{pp} is the peak to peak output voltage excursion)

g) *Ripple and Noise:* Approximately 80 db below peak output or 3 mV, whichever is greater.

h) *Maximum Capacitive Loading:* 0.001 μF.

NOTE: Excessive capacitive loading may result in peaking of the response and instability. Adjustable lag-networks are provided to compensate for a limited range of load reactance.

i) *Regulation and Stability:* All measurements are referred to the input junction. *Voltage* offset is multiplied by one, plus the operational gain: $[E_o = E_{io} (1 + G)]$. *Current* offset is multiplied by the feedback resistance to determine the effect upon the output.

1) *Line Regulation:* Input changes for a 105-125V AC or 210-250V AC line variation are:
(E_{io}) Offset Voltage, smaller than 100 μV.
(I_{io}) Offset Current, smaller than 10 nA.

2) *Load Regulation:* Input changes for a "no load" to "full load" output current change:
(E_{io}) Offset Voltage, smaller than 1 mV.
(I_{io}) Offset Current, smaller than 10 nA.

3) *Stability:* Input changes measured over 8 hours at constant line voltage, load and ambient temperature.
(E_{io}) Offset Voltage, smaller than 10 μV/8 hrs.
(I_{io}) Offset Current, smaller than 50 nA/8 hrs.

4) *Temperature Coefficient:* Input changes measured as a result of temperature changes are:
(E_{io}) Offset Voltage, smaller than 50 μV/°C.
(I_{io}) Offset Current, smaller than 50 nA/°C.

j) *Internal Reference.* A temperature compensated, 6.2V DC (nominal) zener regulated reference voltage is provided together with a fixed input resistance to deliver approximately 1 mA control current to the null junction. Terminals are provided on the output barrier strip which allow insertion of additional input resistance for the purpose of adjusting the control current in the range from 0 to 1 mA.

1) *Reference Regulation:* Less than 0.01% reference voltage shift for 105 to 125V AC or 210 to 250V AC line variation.

2) *Reference Stability:* Less than 0.01% reference voltage shift over 8 hours at constant line voltage and ambient temperature.

3) *Reference Temperature Coefficient:* Less than 0.01% change in reference voltage per °C.

1-11 SPECIFICATIONS, PERFORMANCE

a) *Terminations and Controls:* All Model OPS Operational Power Supplies/Amplifiers contain:

1) Offset Voltage Trimmer
2) Current Limit Control
3) Two adjustable Lag Networks
4) Adjustable Feedback Capacitor

All electrical connections are made via the eleven terminal barrier-strip or the printed circuit board connector. Input and feedback impedances are also externally applied.

b) *Remote Error Sensing:* Terminals are provided at the output barrier-strip, permitting the connection of the sensing leads directly at the load, thus maintaining a low DC source resistance directly at the load terminals. Up to 0.5V DC voltage drop due to load current may be compensated for by remote error sensing.

c) *Cooling:* Heat removal is by natural convection. Perforated vent holes on cased units must not be obstructed. If unit must be installed in confined spaces or crowded racks, care must be taken that the ambient temperature does not exceed the specified range for these models.

1-12 SPECIFICATIONS, PHYSICAL (Refer to Fig. 1-3)

1-13 *Mechanical Dimensions:*

Uncased: $2\frac{1}{2}$"H × $3\frac{13}{16}$"W × $12\frac{13}{16}$"D.

Cased: $2\frac{11}{16}$"H × $4\frac{1}{8}$"W × $13\frac{3}{16}$"D.

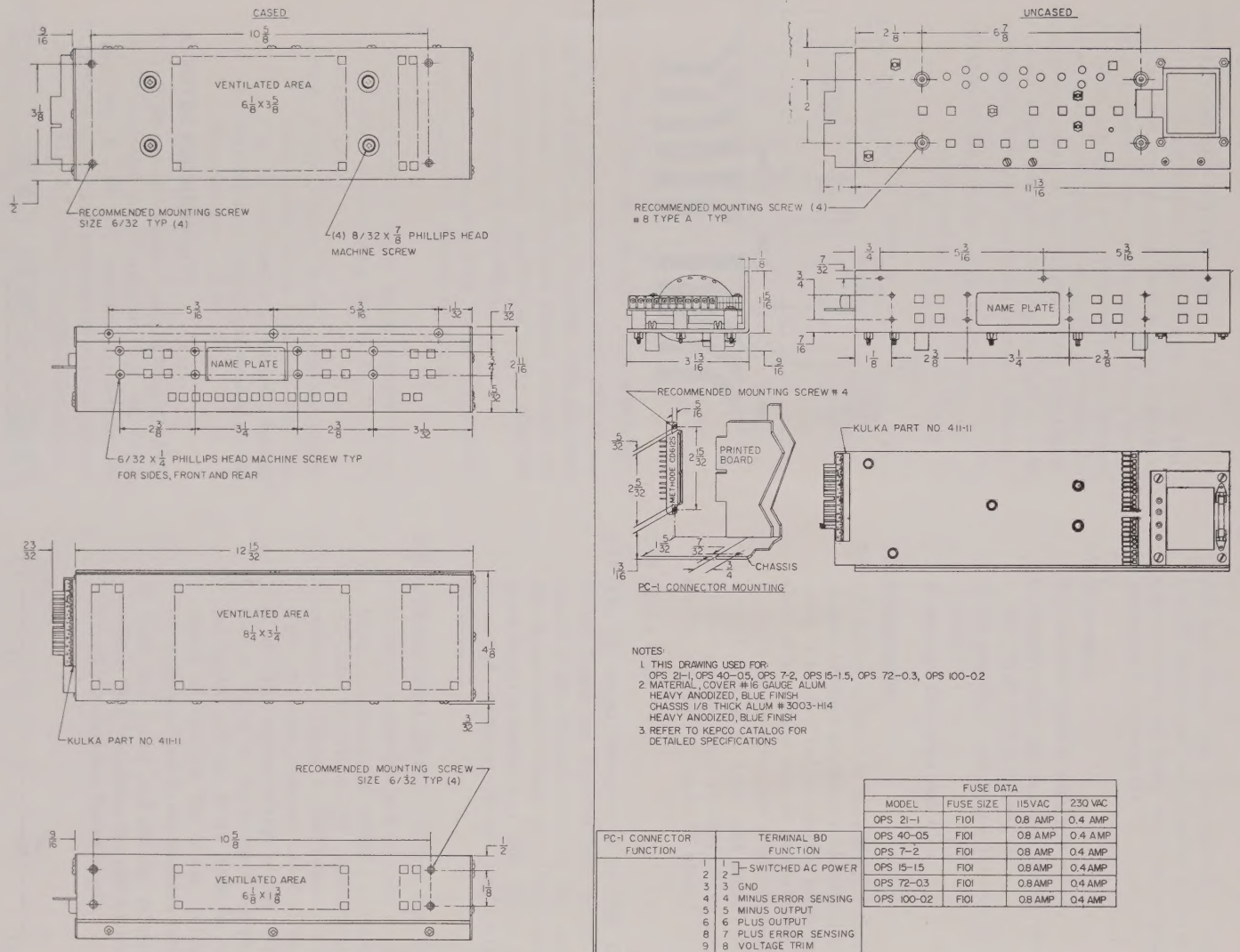


FIG. 1-3 MECHANICAL OUTLINE DRAWING

NOTES:

1. THIS DRAWING USED FOR:
   OPS 21-1, OPS 40-0.5, OPS 7-2, OPS 15-1.5, OPS 72-0.3, OPS 100-0.2
2. MATERIAL, COVER #16 GAUGE ALUM
   HEAVY ANODIZED, BLUE FINISH
   CHASSIS 1/8 THICK ALUM #3003-H14
   HEAVY ANODIZED, BLUE FINISH
3. REFER TO KEPCO CATALOG FOR
   DETAILED SPECIFICATIONS

PC-1 CONNECTOR FUNCTION	TERMINAL BD FUNCTION	
1	1	SWITCHED AC POWER
2	2	
3	3	GND
4	4	MINUS ERROR SENSING
5	5	MINUS OUTPUT
6	6	PLUS OUTPUT
8	7	PLUS ERROR SENSING
9	8	VOLTAGE TRIM
10	9	NULL JUNCTION
11	10	REF. VOLTAGE
12	11	REF. RESISTANCE

FOR ALTERNATE CONNECTIONS SEE KEPCO MANUAL

FUSE DATA			
MODEL	FUSE SIZE	115 VAC	230 VAC
OPS 21-1	F10I	0.8 AMP	0.4 AMP
OPS 40-0.5	F10I	0.8 AMP	0.4 AMP
OPS 7-2	F10I	0.8 AMP	0.4 AMP
OPS 15-1.5	F10I	0.8 AMP	0.4 AMP
OPS 72-0.3	F10I	0.8 AMP	0.4 AMP
OPS 100-0.2	F10I	0.8 AMP	0.4 AMP

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SECTION 2 INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This Operational Power Supply/Amplifier has been inspected and tested at the factory prior to packing and it is shipped ready for operation. After careful unpacking, inspect the instrument for shipping damage before attempting to operate it. Perform the operational check as described in Par. 2-12 below. If there is any indication of damage, file a claim immediately with the responsible transport service.

2-3 TERMINATIONS (Refer to Fig. 2-1)

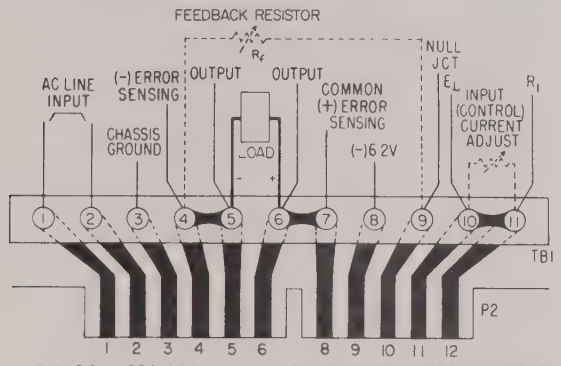


FIG. 2-1: OPS OPERATIONAL POWER SUPPLY TERMINATIONS

2-4 All input and output connections on the OPS Operational Power Supplies are terminated at the miniature barrier strip and the associated printed circuit board connector. Necessary connections to the amplifier can therefore be made two ways:

a) Directly at the barrier strip (correct lugs which fit the individual terminals are supplied),

or

b) Through the printed circuit board connector using the correct mating plug (Refer to Par. 1-5, ACCESSORIES).

NOTE: In the following instructions reference is made to the barrier terminals only. See Fig. 2-1 for correlation between barrier strip terminal numbers and printed circuit connector pin numbers.

2-5 AC POWER REQUIREMENTS

2-6 The OPS Operational Power Supply is normally shipped for operation on a nominal 115V AC single phase line. If 230V AC operation is desired, the transformer primary link connections must be changed as shown in Fig. 2-2 below. For either line voltage, the input connections must be made to terminals (1) and (2), on the rear barrier strip. If a three-wire line cord is used, the third wire (AC ground) must be connected to terminal (3).

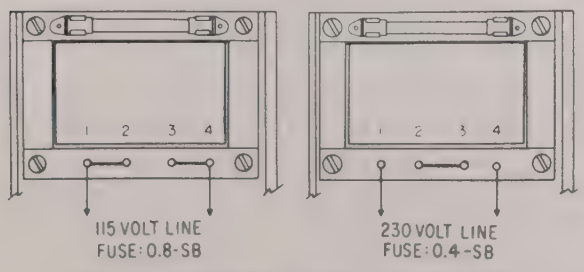


FIG. 2-2: CONVERSION TO 230 V AC LINE OPERATION

2-7 **Procedure:**

a) Disconnect power supply from line.

b) Remove bare wire jumpers between terminals (1) and (2) as well as (3) and (4).

c) Connect bare wire jumper between terminals (2) and (3).

d) Replace 0.8A fuse with 0.4A.

2-8 GROUNDING

2-9 For safety reasons it is imperative that the metal chassis be kept at ground potential. If a three-wire safety line cord and a properly grounded outlet is used, this is taken care of automatically. However, if only a two-wire line cord or an adapter for a three-wire line cord is used, the pigtail wire of the adapter, or the metal chassis of the power supply must be returned to a good AC ground.

2-10 ISOLATION

2-11 The DC output terminals of the OPS Operational Power Supply are isolated from the AC powerline and from the chassis. Since no DC connection to the chassis exists, either side of the supply may be grounded, or a maximum of 500V (DC or p-p) can be connected between chassis and either output terminal.

2-12 OPERATIONAL CHECK (Refer to Fig. 2-3)

a) Connect components and AC input as shown. The Feedback resistor is selected as follows: Shorting terminals (10) and (11) connects the internal reference voltage to the internal reference resistor, providing a control current of approximately 1 mA. The output voltage of the amplifier will then be equal to the feedback resistance times the control current. If the feedback resistor selected is variable, the output voltage may be varied proportional to the feedback resistor.

b) Apply line power and observe voltmeter at the output. This completes the preliminary check of the OPS Operational Power Supply.

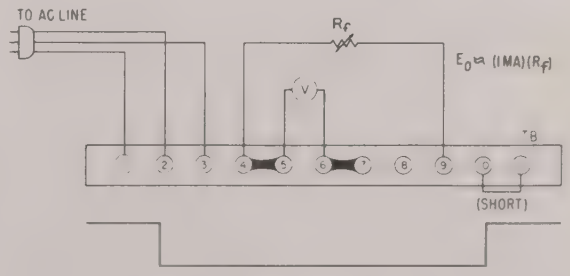


FIG. 2-3: OPERATIONAL CHECK

SECTION 3 SPECIAL OPERATING PROCEDURES

3-1 GENERAL

3-2 The scope of this manual does not allow for a thorough study of operational amplifier theory and the assumption of prior knowledge about the subject must be made. In this section a short review of the more important principles is presented with special reference to the properties of the OPS Operational Power Supplies.

3-3 The term "Operational Amplifier" has originated in the field of analog computing to describe devices performing various mathematical "operations." These devices were high gain DC amplifiers, stabilized with negative feedback to produce gain characteristics that depended only on the amount of feedback used. As the development of these "operational amplifiers" continued, their practical usefulness increased beyond the performance of simple mathematical operations and has been extended to include innumerable functions in all fields of science.

3-4 *Feedback:* As with all feedback amplifiers, the operational amplifier achieves its superior operating characteristics by virtue of its high open loop gain. Feedback is applied to the amplifier by means of proportioning resistors R_1 and R_f. If sufficient feedback is present, the closed loop characteristics of the amplifier become a function of the feedback elements only.

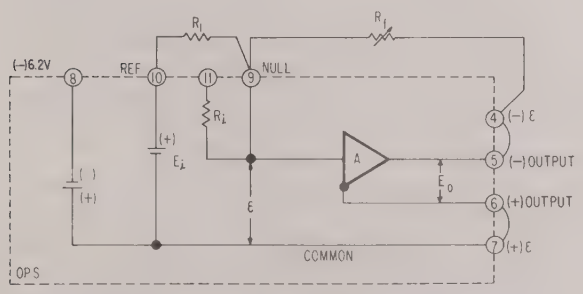


FIG. 3-1: OPERATIONAL AMPLIFIER WITH FEEDBACK

3-5 THE IDEAL OPERATIONAL AMPLIFIER

For the purpose of analysis of an ideal operational amplifier the following assumptions are usually made:

1) The input terminal (null) will not conduct current to the amplifier.
2) The open loop gain is very large. $(A \to \infty)$.
3) The input voltage ε approaches zero when the feedback loop is closed.

Refer to Fig. 3-1. Since the current in R_f and R_1 is the same:

$$\frac{E_i}{R_1} + \frac{E_o}{R_f} = 0$$

and by definition $E_o = -A\varepsilon$

$$\varepsilon = \frac{-E_o}{A}$$

Where A represents the *open loop gain.*

We let $A \to \infty$, so that $\varepsilon \to 0$.

Consequently, $\frac{E_i}{R_1} + \frac{E_o}{R_f} = 0$, or in a more familiar form:

$$E_o = -E_i \frac{R_f}{R_1}$$

Where $\frac{R_f}{R_1}$ represents the *closed loop gain* G.

The closed loop gain or "operational" gain G is nearly independent of the open loop gain A (provided $A \gg G$) the loop gain is the gain difference between open- and closed-loop gain: [A (db) – G (db)].

3-6 PRACTICAL CONSIDERATIONS

It can be shown that the closed loop gain relations derived here are in fact applicable to practical circuitry. The reason for this is that modern operational amplifiers, approach the ideal conditions very closely; they have a very high gain (>80 db in the case of OPS) and very low leakage, which in addition may be compensated for. Other assumptions made for the case of the ideal amplifier, such as infinite input impedance and zero output impedance, are not as readily verified in the practical case. The input impedance, since the amplifier is seldom used in open loop configuration, is dependent upon R_1. The output impedance in the practical case is given by the open loop impedance of the output circuit divided by the loop gain [A (db) – G (db)]. The input impedance can be increased to any desired value, by selecting R_1. The limitation here will be the noise pick-up which can be tolerated for the particular application. In integrating circuits, where the input noise is swamped out by a long time constant, R_1 may assume values into the tens of megohms. The minimum input impedance will depend on the current capability of the input source. If the internal reference source is used for E_i, the input current is limited to 1 mA.

3-7 *Selection of Input and Feedback Resistors.* Since the apparent impedance of the actual amplifier (between null junction and common) is nearly zero, the operational circuit may be looked upon as a current driven device. The input voltage E_i may be any value, as long as it is able to deliver the required current through the input resistor selected. The common order of component selection will usually take place in the following manner:

1) Selection of output voltage desired.
2) Selection of input source.
3) Determination of needed gain ratio.
4) Calculation of R_1 and R_f.

3-8 INTERNAL ADJUSTMENTS

3-9 **Adjustment of Lag Networks in the OPS Operational Power Supply.** The underdamped characteristics of the OPS transfer characteristic may cause ringing, overshoot or excessive noise and oscillation in the output, especially when a squarewave is programmed into a load which is not purely resistive. Any load with a reactive component, may cause distortion in the form of overshoot. To compensate for these effects several adjustable lag-networks are

adjusted from the factory to provide optimum response at all gain ratios, working into a resistive load.

Readjustment for individual load conditions to obtain critical damping or minimum overshoot and stable operation should be performed at minimum gain ratio, using a test set-up as shown in Fig. 3-2. For physical location of the lag-network adjustments refer to Fig. 5-2.

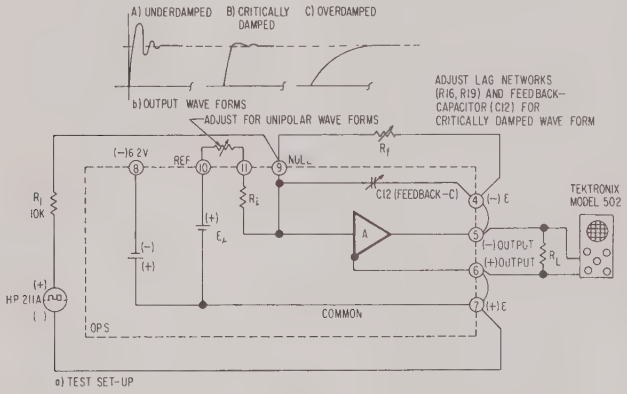


FIG. 3-2: LAG NETWORK ADJUSTMENTS

One of the lag-networks, C12, is in the form of a variable trimming capacitor across the feedback terminals. Its range has been established by assuming a maximum control bridge current of 1 mA. If larger currents are employed – necessitating smaller values for R_f, an external capacitance across R_f may be needed to pad C12 to provide critical damping. This additional capacitor should have a voltage rating greater than the OPS's maximum output voltage.

3-10 Voltage- and Current-Offset Adjustments.

a) Two more non-ideal characteristics are encountered with practical operational amplifiers. Considering the inverse amplifier equation which was derived in Par. 3-5, we see that if $R_f = 0$, E_o should also be zero:

$$E_o = -E_i \frac{R_f}{R_1}$$

A small offset voltage is however measured at the output terminals, even with the feedback resistor R_f shorted out ($R_f = 0$). The cause of this offset voltage are the different V_{be} voltages of the input transistors. A zeroing control R19 is provided in the OPS to cancel the offset voltage and to precision zero the amplifier. Proper zeroing is accomplished by shorting the feedback terminals and adjusting R19 (refer to Component Location Drawing, Fig. 5-4) until a sensitive voltmeter at the output terminals reads exactly zero volts. (Refer to Fig. 3-3.)

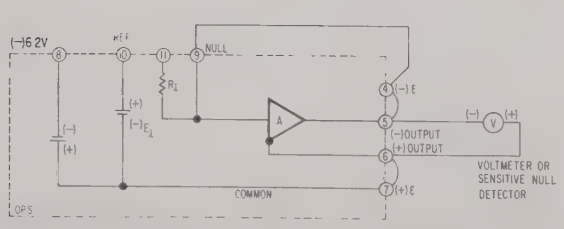


FIG. 3-3: VOLTAGE OFFSET ADJUSTMENT

b) There should be zero current flowing through the feedback element once the input voltage is removed from the circuit. A small loop or offset current is, however, flowing through R_f and will produce an output voltage proportional to R_f and the offset current. This voltage will be particularly significant when R_f is large. Provisions are made in the OPS to compensate for the offset current. (Refer to Fig. 3-4.)

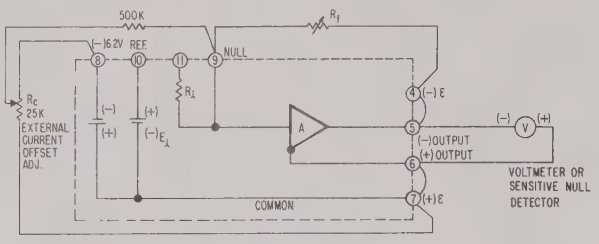


FIG. 3-4: CURRENT OFFSET ADJUSTMENT

The output is connected to a sensitive voltmeter. Disconnect the input voltage E_i and increase R_f in successive steps, R_c (the trim adjustment) should be adjusted for zero output on the voltmeter. As R_f is made large, the sensitivity of the adjustment becomes progressively greater. For example, if R_f is 1 megohm, one volt of output represents only 1 microampere of offset current. With care, the offset can be reduced to a few nanoamperes (1 nanoampere equals 1 millivolt across 1 megohm). Offset current compensation results in raising the input impedance looking into the feedback terminals. This is especially advantageous when the OPS is connected as an impedance transformer, since the feedback terminals serve as the "input" of the circuit. "Impedance" in this case is directly proportional to the residual *leakage current.* With careful adjustment, the input impedance can be raised to 10^7 to 10^8 ohms.

3-11 OPERATION INTO CAPACITIVE LOAD

3-12 The Kepco Operational Power Supply/Amplifier is designed to drive reactive loads, but will tolerate capacitance only up to 0.001 μF as specified. Oscillatory conditions which occur with loads up to this limit can usually be corrected by methods described in Paragraph 3-9 (Lag-Network Adjustments). If one desires to drive larger capacitive loads several techniques can be employed, including the use of additional capacitance across the feedback terminals (9) and (5), alteration of the internal lag networks or isolation resistance in series with the load. The latter method may be used in two variations:

a) *Series resistor external to feedback loop.*

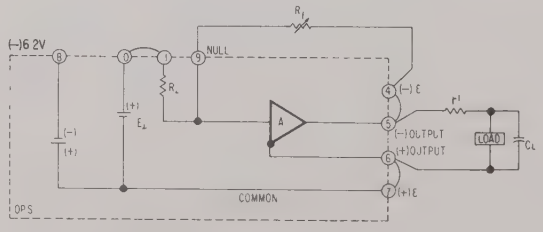


FIG. 3-5: SERIES RESISTOR EXTERNAL TO FEEDBACK LOOP

The advantage of this method is that the network equations, including bounding (if any) are not affected. The disadvantage of this method is the rise

in output impedance, evidenced by degraded load regulation.

b) *Series resistor inside the feedback loop.*

The advantage here is that load regulation is not affected. The disadvantage of this method is that the isolation resistor must be considered part of the feedback resistance R_f and enters the Operational Amplifier equation:

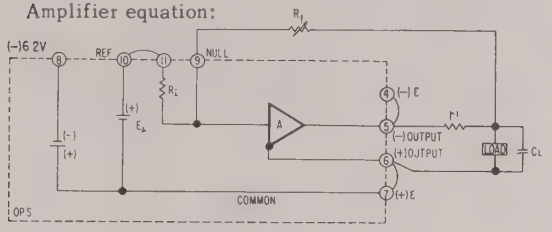


FIG. 3-6: SERIES RESISTOR PART OF FEEDBACK LOOP

$$E_o = -E_i \frac{R_f + r'}{R_1}$$

Also, the voltage drop across r' is of course lost and must be subtracted from the maximum output voltage of the OPS. When using this technique C11 and CR19, across terminals (4) and (5) must be disconnected from the printed circuit board.

3-13 The method suited for a particular load and the desired dc accuracy should be selected according to the importance of the relative advantages and disadvantages as described.

The *best* technique for assurance of stability consists of minimizing load capacitance as much as possible since any method has the disadvantage of narrowing the amplifiers bandwidth and reducing the slewing rate of the OPS Operational Power Supply.

SECTION 4 BASIC OPS CIRCUITS

4-1 GENERAL

4-2 The following circuits represent basic operational amplifier circuits illustrating the versatility of the OPS Operational Power Supply. Encircled numbers represent actual barrier-strip terminal numbers. Refer to Fig. 2-1 for the relationship between these terminal numbers and connector.

4-3 a) Schematically, the OPS Operational Power Supply is represented as a high gain inverting amplifier with gain A.

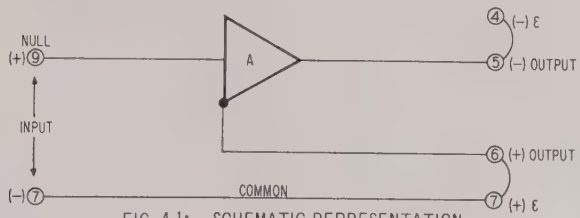


FIG. 4-1: SCHEMATIC REPRESENTATION

b) OPS as an operational amplifier with adjustable gain (Operational Power Supply). The operational gain G equals R_f/R_1 and the input impedance (Z) = R_1.

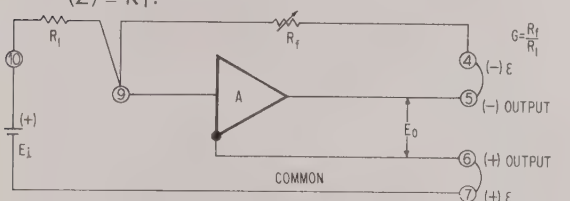


FIG. 4-2: OPERATIONAL POWER SUPPLY

c) OPS Operational Power Supply as an impedance transformer is connected as a unity-gain, non-inverting amplifier. The input impedance depends upon the cancellation of the offset current. (Refer to Par. 3-8.)

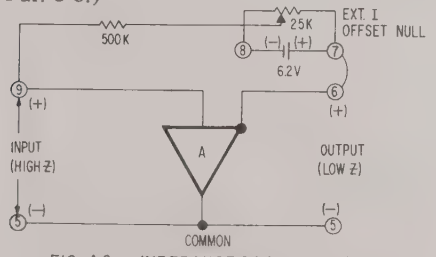


FIG. 4-3: IMPEDANCE TRANSFORMER

d) OPS Operational Power Supply as a Resistance to Voltage Translator. The built-in reference supply is utilized to supply a constant current (selectable) to the source resistor. The output voltage is the product of this current, times the source resistance and thereby linearly related to resistance.

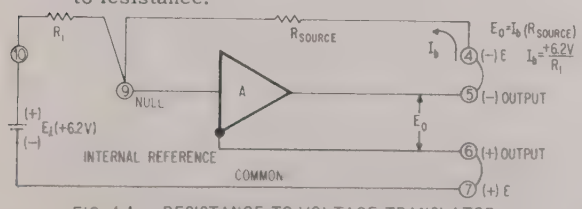


FIG. 4-4: RESISTANCE TO VOLTAGE TRANSLATOR

e) Standard Cell Repeater. The standard cell is connected across the feedback terminals. From the output terminals, current can now be drawn, which is not possible from the standard cell alone. Offset current adjustment (refer to par. 3-8) will reduce the cell leakage to a few nanoamperes.

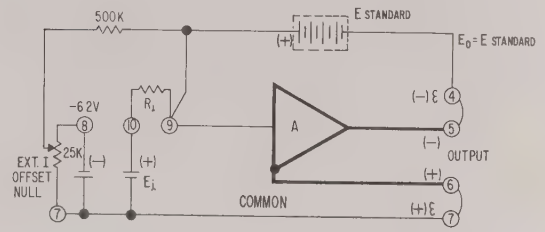


FIG. 4-5: STANDARD CELL REPEATER

f) Constant Current Source, Adjustable with Resistance. The internal reference source is used to produce a control current I_b. R_s is an external current sensing resistor. R_{cc} is the control element. $I_b = \frac{6.2V}{R_1}$ and $I_o = I_b \frac{R_{cc}}{R_s} + I_b$.

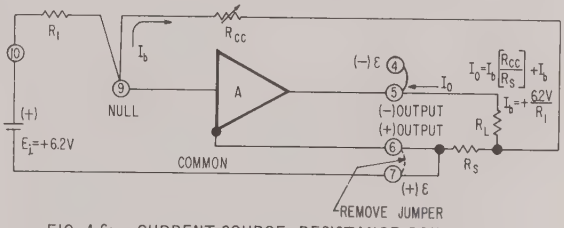


FIG. 4-6: CURRENT SOURCE, RESISTANCE CONTROLLED

g) Constant Current Source, Adjustable by Voltage. The output current here is equal to the ratio of the control voltage E_{cc} to the current sensing resistor R_s: $I_o = \frac{E_{cc}}{R_s}$.

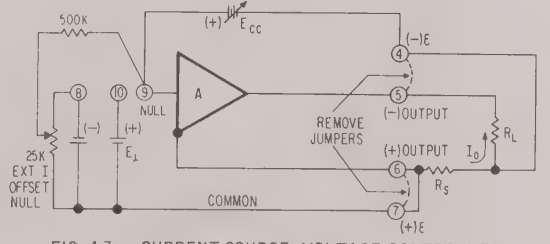


FIG. 4-7: CURRENT SOURCE, VOLTAGE CONTROLLED

h) OPS Operational Power Supply as an Integrator. Special attention must be given in this circuit to the voltage offset adjustment as described in Par. 3-10. The integrating capacitor must be of very high quality (Mylar, Polystyrene, or equivalent). The output voltage will be equal to:

$$E_o = \frac{1}{RC} \int E_i \, dt.$$

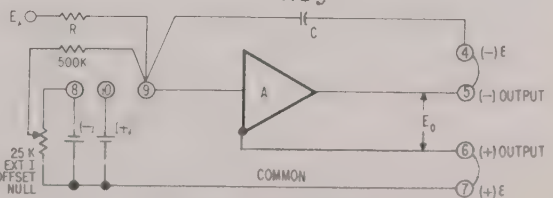


FIG. 4-8: INTEGRATOR

i) OPS Operational Power Supply as a Summer. In the summing circuit shown, the output voltage is equal to:

$$E_o = R_f\left(\frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3}\right)$$

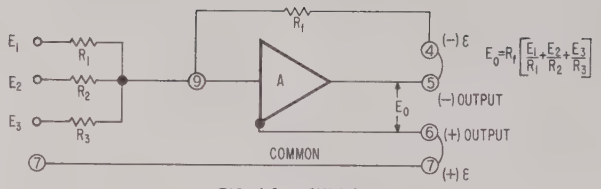


FIG. 4-9: SUMMER

SECTION 5 MAINTENANCE

5-1 GENERAL

5-2 Conservative rating of all components and avoidance of congested layout in the KEPCO OPS Operational Power Supply/Amplifier should keep maintenance to a minimum. If component failure does take place, however, the ease of disassembling the printed circuit board, in conjunction with the provided component layout drawings and information contained in this section, should help minimize the "down time" of this equipment.

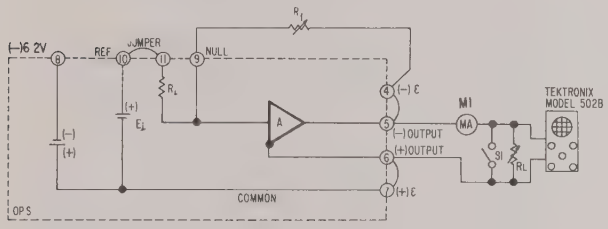


FIG. 5-1: CONNECTIONS FOR CURRENT LIMIT CALIBRATION

5-3 CURRENT LIMIT CONTROL CALIBRATION

5-4 The single-turn control R30, located on PCB-1 (refer to Fig. 5-2) serves as an adjustment for limiting the output current through the range from approximately 10% to 110% of the maximum output current. Although an adjustment beyond 110% may, due to component tolerances, be possible, great care should be taken that this limit is not exceeded. Overheating of components and breakdown may be the result.

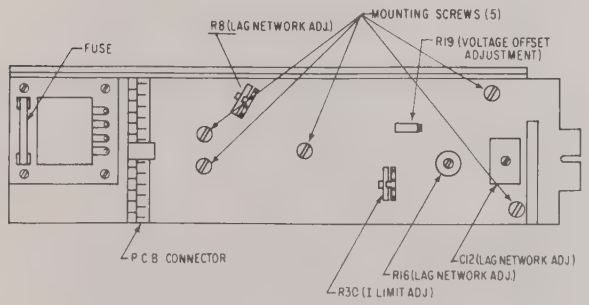


FIG. 5-2: LOCATION OF ADJUSTMENT POTENTIOMETERS. LOCATION OF MOUNTING SCREWS

5-5 Procedure, Current Limit Calibration

a) Connect test set-up as shown in Fig. 5-1.

b) Turn the OPS on, and adjust R_f to the desired output voltage. Adjust load resistor R_L to draw the desired output current, plus approximately 5%.

c) Slowly rotate R30, until the output ripple, as observed on the oscilloscope, increases. Back off slightly on R30 until the ripple appears normal again.

d) Close S1. The short circuit current as read out on ammeter M1, will be approximately equal to the adjusted load current, plus ≈5 mA.

5-6 TROUBLE SHOOTING

5-7 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the problem involved as well as experience with solid state circuitry and closed loop systems. "Trouble Shooting Charts," which give resistance and voltage readings in various places in the circuitry are of little value in feedback amplifiers and are for this reason not included here. Presented instead are:

a) An extensive operational theory (Section III)

b) A circuit description (Par. 5-12)

c) Detailed diagrams showing adjustment and parts location

d) Main Schematic showing the complete circuitry of the OPS Operational Power Supply and a complete parts list.

5-8 It has been found in our experience, that in many cases of malfunctioning, the trouble can be traced to external causes. It is suggested that if trouble is encountered, the OPS is set up as an operational power supply as shown in Fig. 5-1, but without a load. After the test set-up is completed, check the following points:

a) NO OUTPUT. Check AC input line for correct line voltage. Check fuse (see Fig. 5-2 for location). Compare carefully the terminal numbers of the circuit symbols as given in Fig. 2-1.

b) HIGH OUTPUT. Check correct ratio of R_f/R_1. Make certain both input and feedback resistors are connected to their proper terminals. Test transistors. Check reference voltage (nominal 6.2 volts).

5-9 If the OPS works well as a power supply as described in Par. 5-8, and trouble is encountered under programming with a square-wave generator, or oscillation persists, the lag-network settings should be checked and readjusted if discrepancies between input signal and output voltage are observed. (Refer to Paragraph 3-9.) In case of oscillations, as observed at the output, if resetting the lag-networks will not correct it, an additional feedback capacitor (C12) is provided across the feedback terminals. Adjust for critical damping. Although the response time or slewing rate will suffer somewhat, in many cases this compromise may be helpful.

5-10 The Main Schematic (Fig. 5-5) shows the voltage readings for all reference voltages and the more important operating voltages for the OPS as measured with the unit as a power supply. These values are nominal and may differ from the noted values approximately +10%.

5-11 It is hoped that this material will provide the necessary information in case of malfunction. Kepco Field Engineering Offices and the Kepco Repair Dept. are always available for prompt service in difficult cases.

5-12 CIRCUIT DESCRIPTION

(Refer to Main Schematic, Fig. 5-5)

5-13 The OPS Operational Power Supply/Amplifier consists essentially of a three terminal, high gain DC

amplifier. The output capability of the OPS is determined by the electrical dimensions of its power-supply. For the purpose of analysis the OPS may be conveniently divided into several sections which are described in detail below.

a) *The Main Power Supply.* The DC power, determining the output capability of the OPS Operational Power Supply/Amplifier is derived from a centertapped winding on T201, full-wave rectified by CR1 and CR2 and capacitive filtered by C3 and C4.

b) The *pass element* (or series control transistor) Q201 is connected in series with the positive output terminal so that the unregulated voltage from the rectifier circuit is divided between it and the load. By changing the equivalent series resistance of the pass element, the voltage drop across it is made to change in such a way as to maintain a constant output voltage. The base drive necessary to effect this change is supplied by driver Q3, which in turn is driven by the control signal from the amplifier. OPS Operational Power Supplies above 0.5 Ampere output current have an additional pass element (Q202), parallel to Q201.

c) *The DC Amplifier.* This three-stage, DC coupled amplifier consists of Q7, Q8, and Q2. It is temperature compensated and its common terminal is referred to the positive error sensing terminal. The AC compensation of the amplifier is made variable through adjustable lag networks R8 and R16, as well as through the variable capacitor (C12) across the feedback terminals. The complementary input pair (Q7, Q8) with the voltage amplifier stage (Q2) supply the necessary input signal amplification to drive Q3, the main driver transistor.

d) *The Reference Circuit.* The reference, or auxiliary input voltage, is derived from a temperature compensated zener diode (CR15) which is fed from the precision regulated amplifier power supply, resulting in an extremely stable and highly regulated source, available at the rear-barrier strip for purposes of input biasing, or used as internal reference voltage when the OPS is used as an operational power supply rather than an amplifier.

e) *The Amplifier Power Supply.* This full wave, capacitor filtered source is derived from a centertapped winding on T201. CR1 and CR2 are the rectifiers and C1 the filter capacitor. A series regulator stage (Q1) followed by four zener diodes (CR9, CR10, CR11, and CR12) provide exceptionally stable operating voltages for the amplifier.

f) *Compensating Source.* An additional zener (CR16) regulated voltage is available at the rear-barrier strip. This voltage, derived in the identical way as the reference voltage, is provided for the purpose of offset current compensation.

g) *Current Limit Circuitry.* The exceptionally sharp current cut-off characteristics of the OPS Operational Power Supply was achieved by the design of a unique limiting circuit comprised of three stages. Q5 and Q6 are connected as a differential pair. The base of Q6 is referred to the "Current Limit" potentiometer (R30), while the base of Q5 senses the voltage across current sensing resistor R11. As long as the voltage drop across R11 (due to the output current) does not exceed the voltage value selected by the setting of R30, Q6 is conducting and keeps Q4 in the cut-off condition. Q4 therefore plays no part under normal operating conditions. If an overcurrent causes a rise of voltage across R11, the base of Q5 becomes more positive and Q5 starts to conduct, while Q6 is simultaneously driven towards cut-off. In consequence, Q4 will now also conduct and due to its increased collector current, pull Q202 and Q203 towards a direction tending to cut off the pass element(s) Q101 (Q102), thus sharply limiting the output current.

h) *Driver Collector Supply.* This half-wave, capacitor filtered supply is derived from a winding on T201, rectified by a silicon rectifier (CR3) and filtered by C2. It delivers collector voltage to driver transistor Q3.

i) I_{co} *Supply.* This full-wave, capacitor filtered supply is derived from the same winding on T201 which supplies the main DC power. CR5 and CR7 are the rectifiers, C5 is the filter capacitor. This supply has the function of providing the turn-off bias for the series pass transistor(s), especially at elevated ambient temperatures.

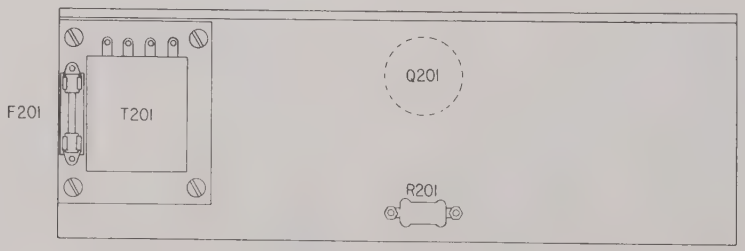


FIG. 5-3: COMPONENT LOCATION, MAIN CHASSIS

NOTE:

1. R31 is used in OPS 7-2, OPS 15-1.5 & OPS 21-1.
2. C15 is used in OPS 7-2 & OPS 21-1.
3. C10 & R25 is used in OPS 7-2 & OPS 15-1.5.

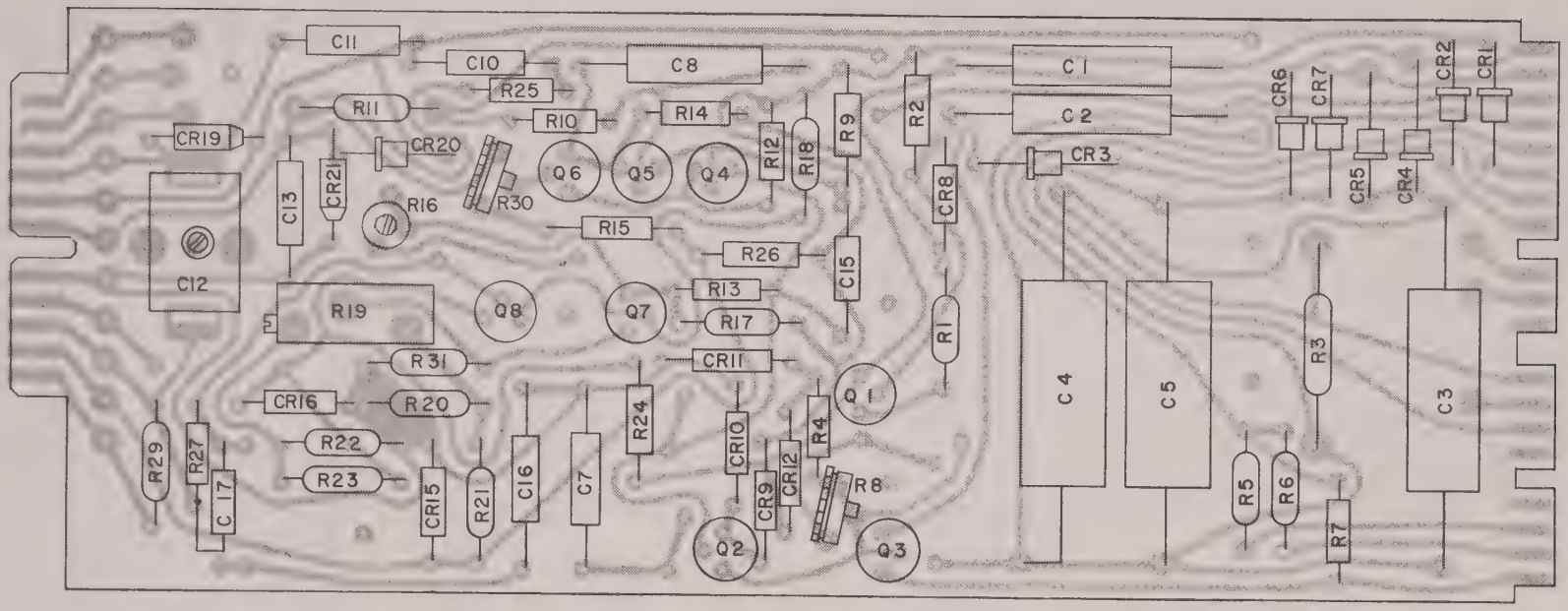
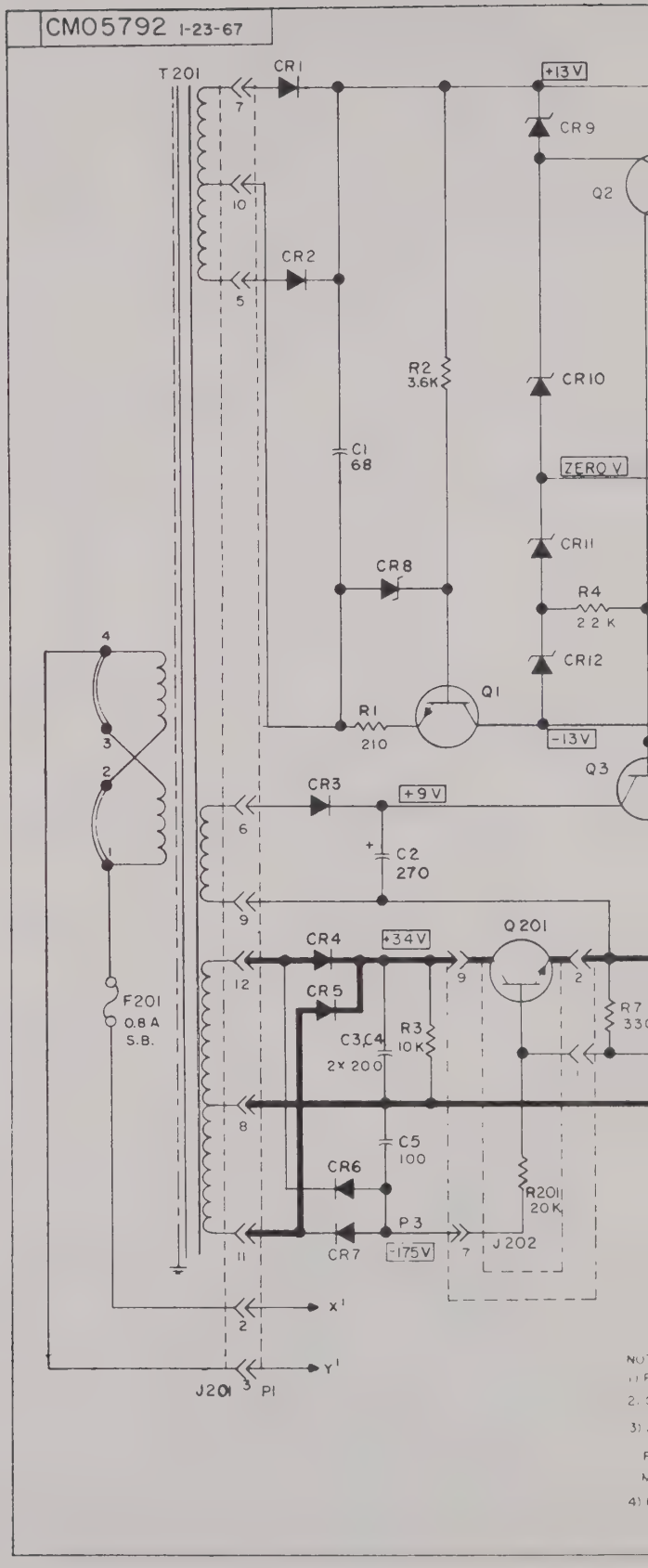
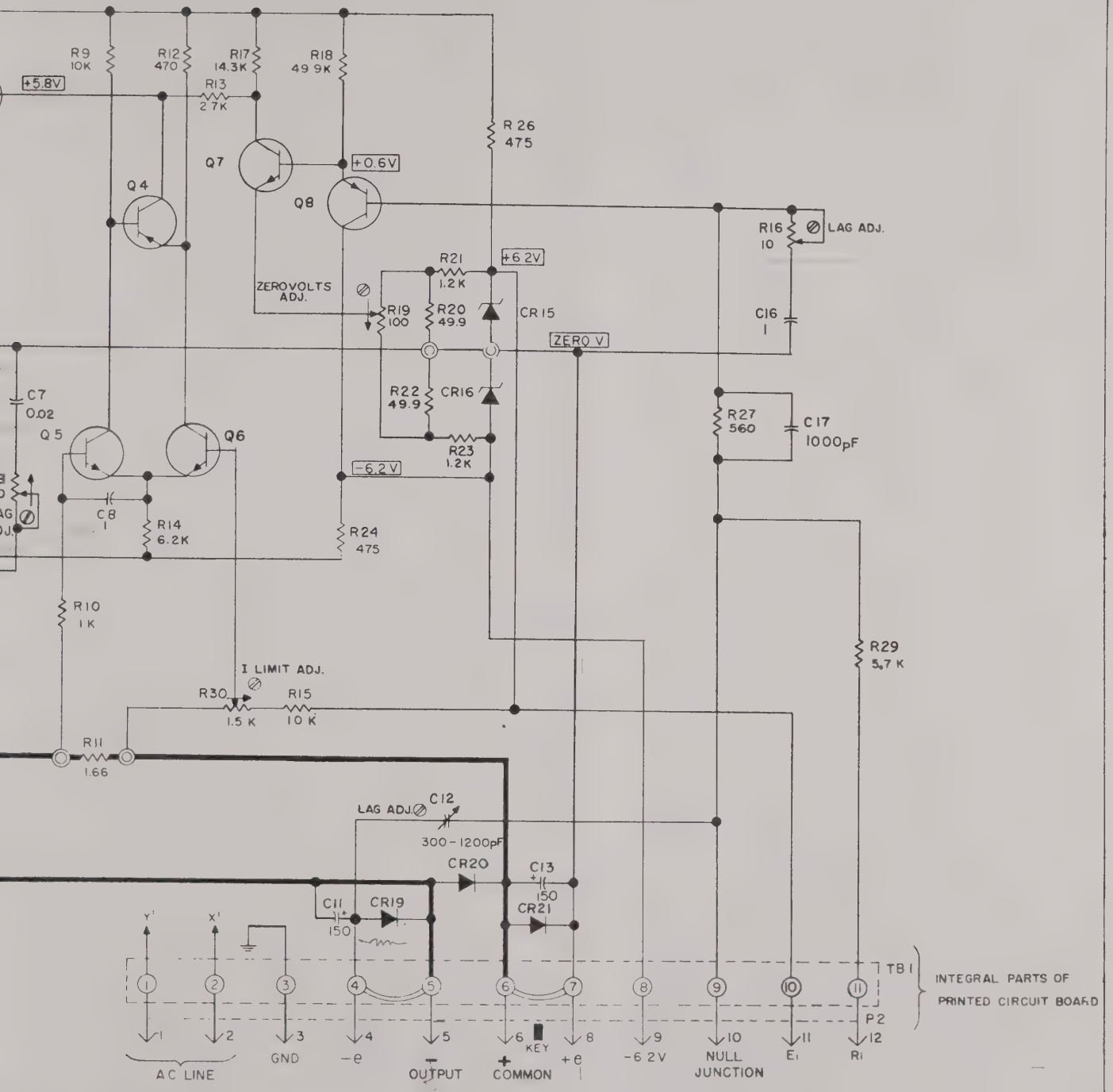


FIG. 5-4: COMPONENT LOCATION, PRINTED CIRCUIT BOARD


CM05792 1-23-67
T201
CR1
+13V
CR9
Q2
CR2
R2
3.6K
CR10
C1
68
ZERO V
CR11
CR8
R4
22K
CR12
Q1
R1
210
-13V
Q3
CR3
+9V
C2
270
Q201
CR4
+34V
CR5
F201
0.8A
S.B.
C3,C4
2x200
R3
10K
C5
100
CR6
R201
20K
P3
CR7
-175V
J202
X1
Y1
J201
P1



OR VALUES IN OHMS (K = 1000)

TOR VALUES IN MICROFARADS, EXCEPT AS OTHERWISE INDICATED.

E MEASUREMENTS WITH 20K/V METER,

NCED TO (+) OUTPUT (COMMON) TERMINAL

OUTPUT VOLTAGE, NO LOAD

P3 ARE INTEGRAL PARTS OF THE PRINTED CIRCUIT BOARD

202 ARE PARTS OF THE MAIN CHASSIS ASSEMBLY

kepco

Data subject to change without notice
PATENT NOTICE: Applicable Patent Nos. will be supplied on request.

FIG. 5-5 MAIN SCHEMATIC, MODEL OPS 72-0.3

REPLACEMENT PARTS LIST

PRINTED CIRCUIT BOARD ASSEMBLY (235-0233) MODEL OPS 72-0.3 (C) Code 10-1866

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
C1	1	Capacitor, Electrolytic, Pigtail 68 μF, 50 V, 20%	General Electric 76F02LN680	117-0511
C2	1	Capacitor, Electrolytic, Pigtail 270 μF, 12 V, 20%	General Electric 76F-2EN271	117-0510
C3,4	2	Capacitor, Electrolytic, Pigtail 200 μF, 150 V	General Electric 43F7581AA1	117-0440
C5	1	Capacitor, Electrolytic, Pigtail 100 μF, 150 V	General Electric 43F2649AA2	117-0140
C7	1	Capacitor, Mylar, Pigtail 0.02 μF, 200 V, 10%	Sprague 192P20392	117-0377
C8,16	2	Capacitor, Mylar, Pigtail 1 μF, 200 V, 10%	Wesco 33MM	117-0395
C11,13	2	Capacitor, Electrolytic, Pigtail 150 μF, 3 V, 20%	General Electric 76F02BF151	117-0512
C12	1	Capacitor, Variable 300 - 1200 μμF	Arco 4613	117-0572
C17	1	Capacitor, Mylar, Pigtail 1000 pF, 200 V, 10%	Sprague 192P10292	117-0570
CR1,2,3	3	Rectifier, Silicon, Pigtail	Semicon Inc. SM-110	124-0133
CR4,5,6, 7,20	5	Rectifier, Silicon, Pigtail	Semicon Inc. SM-140	124-0028
CR8,9,10, 11,12	5	Zener Diode	Transitron SV125	121-0028
CR15,16	2	Zener Diode	International Rect. 1N821	121-0041
CR19,21	2	Rectifier, Silicon, Pigtail	Solitron 124-0178	124-0178
Q1	1	Transistor, Silicon, NPN	RCA 2N3053	119-0059
Q2,4,8	3	Transistor, Silicon, PNP	Hughes 2N1131A	119-0055
Q3,5,6,7	4	Transistor, Silicon, NPN	General Electric 2N336A	119-0056
R1	1	Resistor, Fixed, Precision 210 ohm, 1 W, 1%	IRC Type CES	115-1936
R2	1	Resistor, Fixed, Molded 3.6 K ohm, 1 W, 5%	Allen Bradley EB3625	115-0635
R3	1	Resistor, Fixed, Power, Axial 10 K ohm, 5 W, 5%	Hardwick Hindle 853	115-0446

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

kepco inc. ® REPLACEMENT PARTS LIST

PRINTED CIRCUIT BOARD ASSEMBLY (235-0233) MODEL OPS 72-0.3 (C) Code 1-2367

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
R4	1	Resistor, Fixed, Power, Axial 22 K ohm, 1/2 W, 10%	Allen Bradley EB2231	115-0260
R7	1	Resistor, Fixed, Molded 330 ohm, 1/2 W, 5%	Allen Bradley EB3315	115-1086
R8	1	Resistor, Variable, Composition 500 ohm, 1/4 W, 30%	C.T.S. X201 Series	115-1972
R9	1	Resistor, Fixed, Molded 10 K ohm, 1/2 W, 10%	Allen Bradley EB1031	115-0489
R10	1	Resistor, Fixed, Molded 1 K ohm, 1/2 W, 5%	Allen Bradley EB1025	115-0340
R11	1	Resistor, Fixed, Power, Axial 1.66 ohm, 3 W, 3%	Tepro TS3W	115-1879
R12	1	Resistor, Fixed, Molded 470 ohm, 1/2 W, 5%	Allen Bradley EB4715	115-0919
R13	1	Resistor, Fixed, Molded 2.7 K ohm, 1/2 W, 5%	Allen Bradley EB2725	115-1085
R14	1	Resistor, Fixed, Molded 6.2 K ohm, 1/2 W, 5%	Allen Bradley EB6225	115-0744
R15	1	Resistor, Fixed, Precision 10 K ohm, 1 W, 1%	IRC Type CES	115-1821
R16	1	Resistor, Variable, Cermet 10 ohm, 1/2 W, 30%	Beckman 62PR10	115-2036
R17	1	Resistor, Fixed, Precision 14.3 K ohm, 1 W, 1%	IRC Type CES	115-1934
R18	1	Resistor, Fixed, Precision 49.9 K ohm, 1 W, 1%	IRC Type CES	115-1857
R19	1	Resistor, Variable, Cermet 100 ohm, 3/4 W, 20%	Beckman 75PR100	115-1979
R20, 22	2	Resistor, Fixed, Precision 49.9 ohm, 1 W, 1%	IRC Type CES	115-1938
R21, 23	2	Resistor, Fixed, Precision 1.21 K ohm, 1 W, 1%	IRC Type CES	115-1937
R24, 26	2	Resistor, Fixed, Precision 475 ohm, 1 W, 1%	IRC Type CES	115-1935
R27	1	Resistor, Fixed, Molded 560 ohm, 1/2 W, 10%	Allen Bradley EB5611	115-0451
R29	1	Resistor, Fixed, Precision 5.7 K ohm, 1 W, 1%	Tepro TS1W	115-1301
R30	1	Resistor, Variable, Composition 1.5 K ohm, 1/4 W, 30%	C.T.S. X201 Series	115-1939

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

kepco inc. ® REPLACEMENT PARTS LIST

MAIN CHASSIS, MODEL OPS 72-0.3 (C) Code 3-2966

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (See Note)	KEPCO PART NO.
F201	1	Fuse, Slo Blo 0.8 A	Bussman MDL-8/10	141-0027
Q201	1	Transistor, Silicon, NPN	RCA 2N3442	119-0070
R201	1	Resistor, Fixed, Power, Strip 20 K ohm, 20 w, 5%	Hardwick Hindle B-465	115-0853
T201	1	Transformer	Kepco Magnetics	100-1576

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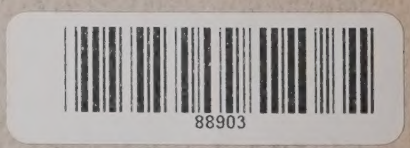

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